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Coastal Megacities and Climate Change

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ABSTRACT: Rapid urbanization is projected to produce 20 coastal megacities (population exceeding 8 million) by 2010. This is mainly a developing world phenomenon: in 1990, there were seven coastal megacities in Asia (excluding those in Japan) and two in South America, rising by 2010 to 12 in Asia (including Istanbul), three in South America and one in Africa.

All coastal locations, including megacities, are at risk to the impacts of accelerated global sea-level rise and other coastal implications of climate change, such as changing storm frequency. Further, many of the coastal megacities are built on geologically young sedimentary strata that are prone to subsidence given excessive groundwater withdrawal. At least eight of the projected 20 coastal megacities have experienced a local or *relative* rise in sea level which often greatly exceeds any likely global sea-level rise scenario for the next century.

The implications of climate change for each coastal megacity vary significantly, so each city requires independent assessment. In contrast to historical precedent, a proactive perspective towards coastal hazards and changing levels of risk with time is recommended. Low-cost measures to maintain or increase future flexibility of response to climate change need to be identified and implemented as part of an integrated approach to coastal management.

Introduction

As well as experiencing a rapid growth in population, the world is seeing a rapid trend of urbanization – by about 2005, half the world's population is expected to live in urban settings, rising to 60% by 2025 (United Nations Population Division 1993). Developed countries are already highly urbanized and most of these changes are occurring in developing countries, including an unprecedented growth in the number of megacities – defined here as cities with a population exceeding 8 million people. There were only 2 megacities in 1950 (New York and London), whereas there were 20 megacities in 1990 and there are a projected 30 megacities by 2010 (United Nations Population Division 1993).

Most of these actual and projected megacities are found in coastal settings where they are susceptible to one of the most certain impacts of anthropogenically-induced climate change – accelerated sea-level rise. Other possible coastal implications of climate change, which will interact with sea-level rise, include changing storm frequency and intensity, changing patterns of run-off and more intense rainfall events (eg, Nicholls et al. 1995). The protection of cities is expected to be a major cost of accelerated sea-level rise (Turner et al. 1990). It would also appear to be one of the more likely responses given the high value of many city areas, although many uncertainties exist (Devine 1992).

It is important to ask what "protection" means in the context of changing hazards and risks with time. Urbanization is occurring much faster than the likely rates of global climate change and the growth of coastal megacities will, in itself, engender many new hazards and problems (Haughton and Hunter 1994). For instance, the environments around many coastal cities are already being degraded (Devine 1992), while the significant growth in insurance claims over the last few decades is partly related to growing coastal populations and urbanization (Berz 1993). However, these hazards will often be exacerbated by global climate change. Therefore, climate change must be seen as a long-term problem that is superimposed on a number of more immediate issues. This paper considers

1960		1970		1980		1990		2000		2010	
New York	14.2	Tokyo	16.5	Tokyo	21.9	Tokyo	25.0	Tokyo	28.0	Tokyo	28.9
Tokyo	11.0	New York	16.2	New York	15.6	New York	16.1	Bombay	18.1	Bombay	24.4
London	9.1	Shanghai	11.2	Shanghai	11.7	Shanghai	13.4	Shanghai	17.8	Shanghai	21.7
Shanghai	8.8	Osaka	9.4	Osaka	10.0	Bombay	12.2	New York	16.6	Lagos	21.1
		London	8.6	Buenos Aires	9.9	Los Angeles	11.5	Lagos	13.5	Dhaka	17.6
		Buenos Aires	8.4	Los Angeles	9.5	Buenos Aires	11.4	Jakarta	13.4	New York	17.2
		Los Angels	8.4	Calcutta	9.0	Seoul	11.0	Los Angeles	13.2	Jakarta	17.2
				Rio de Janeiro	8.8	Rio de Janeiro	10.9	Seoul	12.9	Karachi	17.0
				Seoul	8.3	Calcutta	10.7	Buenos Aires	12.8	Metro Manila	16.1
				Bombay	8.1	Osaka	10.5	Calcutta	12.7	Tianjin	15.7
						Tianjin	9.2	Metro Manila	12.6	Calcutta	15.7
						Jakarta	9.2	Tianjin	12.5	Los Angeles	13.9
						Metro Manila	8.9	Rio de Janeiro	12.2	Seoul	13.8
								Karachi	11.9	Buenos Aires	13.7
								Dhaka	11.5	Rio de Janeiro	13.3
								Osaka	10.6	Bangkok	12.7
								Bangkok	9.9	Istanbul	11.8
								Istanbul	9.3	Osaka	10.6
								Lima	8.4	Lima	10.1
										Madras	8.4
Sum	43.1		78.7		112.8		160.0		257.5		320.9

Tab 1 Coastal megacities and their population (in millions): 1960 to 2010 (from United Nations Population Division 1993)

the implications of climate change for coastal megacities and proto-megacities (ie cities with populations between 2 million and 8 million). It focuses particularly on the opportunities for adopting proactive measures that are designed to increase long-term flexibility in response to an uncertain future.

Coastal Megacities

The data and projections of the United Nations Population Division (1993) are used throughout this paper, providing a consistent global data set of the distribution of megacities from 1950 to 2010 (Tab 1). The definition of a megacity as coastal was simply based on the position of the city relative to the coast, including the likelihood that a 50 cm rise in sea level would have significant physical impacts within the city boundaries. (Other possible factors such as population density and coastal length are not considered systematically, but might be usefully considered in future analyses). While Seoul and Dhaka (otherwise known as Dacca) are not located on the coast per se, the river levels within both cities would rise with sea level increasing the risk of flooding. In contrast, Sao Paulo, the world's second largest megacity in 1990 (population: 18.1 million), is situated 800 m above sea level, so it is not coastal despite being situated less than 50 km from the coast (Muehe and Neves 1995). It seems likely that with continued growth, Sao Paulo will eventually reach the coast, just as Lima – another megacity originally established inland – has recently done (Devine 1992, p. 51).

More generally, some coastal megacities may have been omitted due to the data set utilized. For instance, London is not considered as a megacity after 1970 due to population decline in the core city (United Nations Population Division 1993). However, as Parker (1994) notes, the population of London varies from 6.7 to 13.2 million, or even up to 20 million depending on the geographical boundary chosen. Similarly, New York can be considered part of a larger, more informal megacity – "Megalopolis" – stretching over 400 km from Boston to Washington DC and having a total population of about 47 million people. Hong Kong, Shenzhen and Guangzhou, already with a collective 1990 population of at least 9.0 million, are rapidly coalescing to form one large coastal conurbation. These larger, more dispersed megacities are not explicitly considered here, and so this study presents minimum estimates of the global size and importance of coastal megacities.

The rapid growth of coastal megacities is illustrated in Fig 1 and 2. From two coastal megacities in 1950, the number has increased to 13 by 1990 and is projected to be 20 by 2010. Most growth is in the developing world: from no megacities in 1950, to 9 coastal megacities in 1990 and a projected 16 coastal megacities in 2010. These projections comprise 12 megacities in Asia (excluding those in Japan), three in South America and, for the first time, one in Africa (Lagos).

Coastal megacities had a collective population of 160.0 million people in 1990, rising to a projected 320.9 million people in 2010. They also form a growing proportion of global population: being 3% in 1990, and projected to increase to nearly 4.5% by 2010 (Fig 2). Taking existing trends of urbanization and the fact that coastal populations are growing more rapidly than global populations (World Coast Conference 1994), coastal cities and megacities seem likely to become the major setting for human habitation during the 21st century.

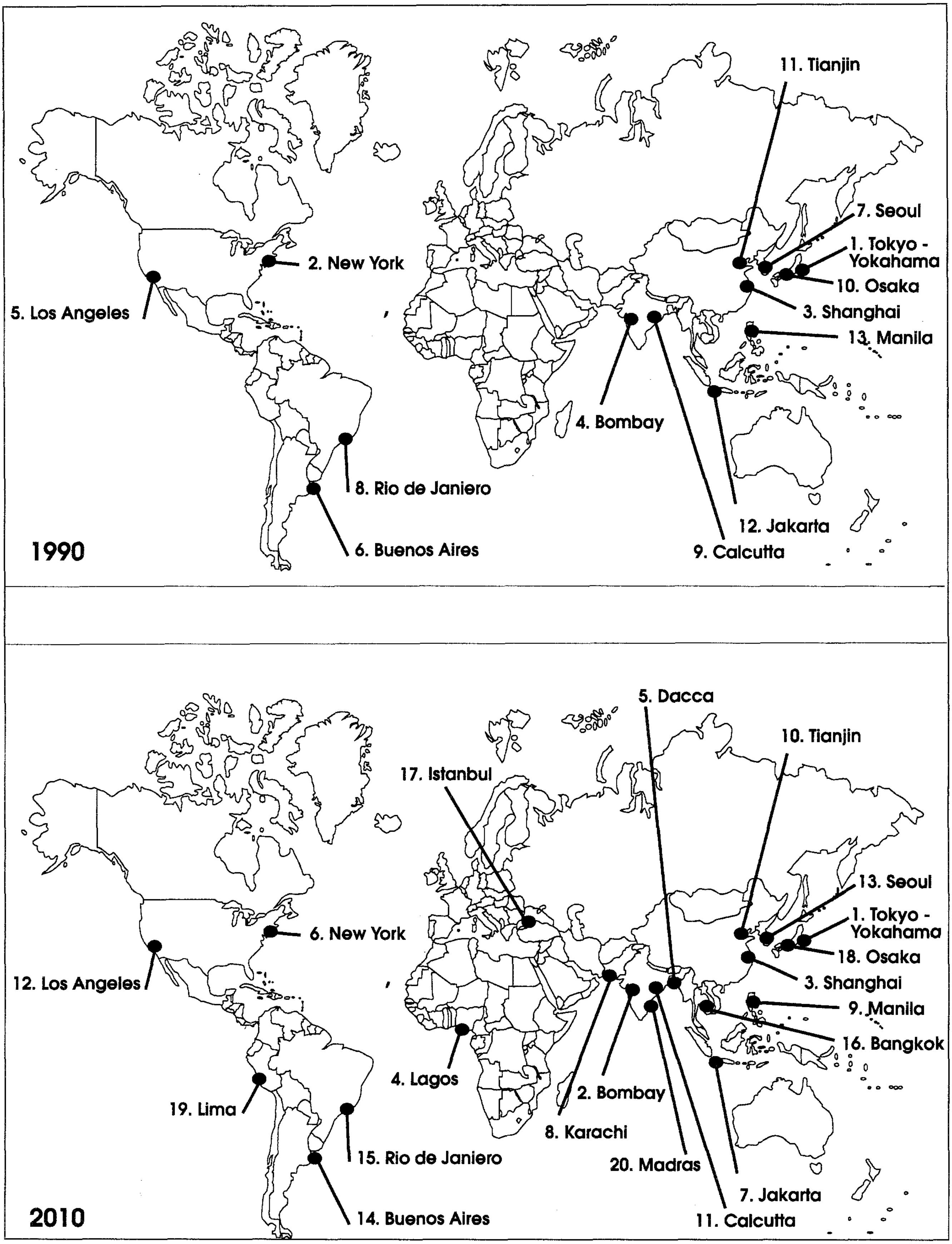

Fig 1 Coastal megacities in 1990 and 2010 (projected). Data derived from United Nations Population Division (1993)

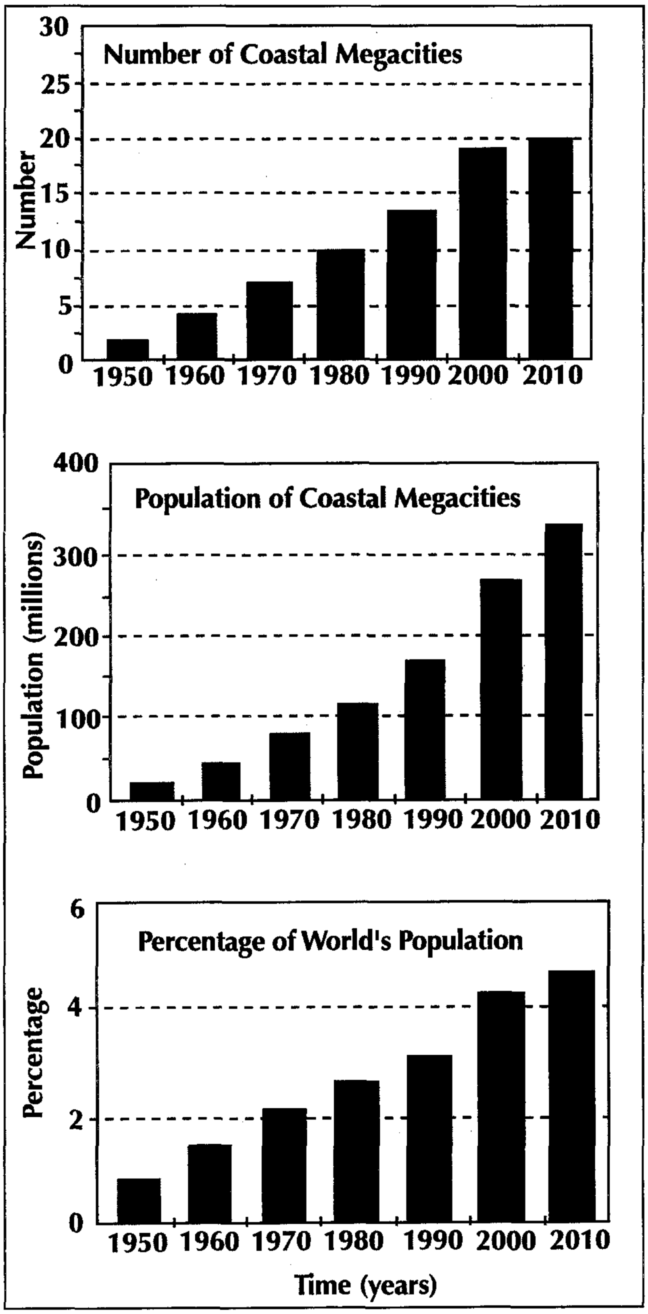

Fig 2 Changes in coastal megacities from 1950 to 2010: (a) Number of coastal megacities; (b) Total population of coastal megacities; and (c) Proportion of global population living in coastal megacities. Data derived from United Nations Population Division (1993)

Global Climate Change

Sea-Level Rise

There is a widespread consensus that global sea levels have risen over the last century at 1 to 2 mm/yr (Warrick and Oerlemans 1990; Gornitz 1995). In addition to global sea-level changes, local uplift or subsidence of the land surface must be considered: the sum of global and local changes are termed relative sea-level change. This is by definition what an observer sees at any particular coastal station. As the sense and magnitude of vertical land movements vary from place-to-place, so relative rates of sea-level change also vary from place-to-place.

In the coming century, accelerated global sea-level rise is expected to occur due to anthropogenic global warming. Given the large uncertainties, a global rise in sea level from about 0.2 to 0.9 m by 2100 appears possible, with best estimates of a rise of about 0.5 m (Wigley and Raper 1992; Warrick 1993) or a 2.5-fold acceleration. The Intergovernmental Panel on Climate Change (IPCC) Working Group I will provide updated scenarios of sea-level rise in its second assessment report, due in December 1995. In the context of megacities, the most serious impacts of sea-level rise are:

1) an increased risk of flooding and impeded drainage;
2) salinization of freshwater supplies;
3) higher water tables which may reduce the safety of foundations; and
4) beach erosion (National Research Council 1987).

Other Coastal Implications of Climate Change

Global climate change may also lead to a change in the frequency and intensity of storms (eg, Emmanuel 1987). Unlike global sea-level rise, storminess is more difficult to predict. The possibility of an increase in storm frequency often causes more concern than sea-level rise (Berz 1993; McLean and Mimura 1993; Nicholls et al. 1995). Equally, a decrease in storm frequency and intensity is possible with widespread benefits. Hence, no generalizations are possible. In addition to wind damage, coastal storms cause storm surges which flood low-lying coastal areas and allow destructive wave action to penetrate inland. At present, at least nine megacities are exposed to the threat of hurricanes or tropical storms (otherwise know as typhoons and cyclones in some parts of the world), three are exposed to significant flooding due to extratropical storms, and four are exposed to both (Tab 2). Given increasing sea surface temperatures with global warming, megacities at the higher latitude extent of hurricane storm tracks such as New York and Tokyo may be subject to an increased frequency of destructive storms.

Global climate model simulations indicate that the return period for heavy rainfall events may decrease given global warming (Gordon et al. 1992). For instance, simulations for South and South-East Asia suggest that heavy rainfall events with a 10-year return period under current conditions, may have a five-year or smaller return period under doubled CO_2 conditions (Whetton et al. 1994). This would intensify flooding, including low-lying coastal areas where the base level will be simultaneously increasing due to sea-level rise. It suggests the need for an increased drainage capacity given global warming, particularly in coastal areas (Nicholls et al. 1995).

Some Existing Problems of Coastal Megacities

The rapid growth of coastal cities creates many immediate problems. Some of these problems are particularly relevant to climate change and are briefly considered here.

Land Use

Pressure on land often leads to less desirable or more flood-prone areas being developed or occupied, particularly in the developing world. Dakar, Senegal evolved on the relatively high land of the Cap Vert Peninsula, but recent growth has occurred on more low-lying land which may be flood-prone. The shorelines are also likely to experience erosion (Dennis et al. 1995). Often the poorest people in each city are found in unauthorized shanty-town areas in the least secure settings, including the megacities of Bombay, Lima, Calcutta, Manila, Karachi, Lagos, Bangkok, Jakarta and Rio de Janeiro (Devine 1992). These shanty-towns are often built in areas that would be affected by sea-level rise, as exemplified in Recife, Brazil, where illegal shanty-town areas (or *favelas*) are invading mangrove areas (Neves and Muehe 1995).

Pressure for land often triggers coastal reclamation such as in Singapore (Chou and Lim 1991) and Hong Kong (Yim 1995); reclaimed areas are generally vulnerable to sea-level rise. Constriction of estuaries can adversely increase tidal and surge characteristics as appears to be the case in London (Kelly 1991) and Hamburg (Ascher 1991).

Megacities	Hurricane Landfall and Relative Frequency	Extra-Tropical Storms
Tokyo	Yes (3)	No
Bombay	Yes (<1)	No
Shanghai	Yes (1)	No
Lagos	No	No
Dhaka	Yes (<1)	No
New York	Yes (<1)	Yes
Jakarta	No	No
Karachi	Yes (<0.1)	No
Metro Manila	Yes (>3)	No
Tianjin	Yes (<0.1)	Yes
Calcutta	Yes (<1)	No
Los Angeles	No	Yes
Seoul	Yes (1 to 3)	Yes
Buenos Aires	No	Yes
Rio de Janeiro	No	No
Bangkok	Yes (<1)	No
Istanbul	No	Yes
Osaka	Yes (3)	No
Lima	No	No
Madras	Yes (<1)	No

Tab 2 Storm characteristics of the coastal megacities (in 2010). To indicate the relative frequency of hurricane landfall, the annual occurrence of tropical storms and cyclones (Beaufort Force 8 and above) is indicated (Source: Munich Reinsurance Company, 1992)

Flooding

As already stated, fifteen of the coastal megacities are exposed to coastal flooding due to storm surges generated either by hurricanes and/or extra-tropical depressions (Tab 2). This type of threat has generally triggered the construction and progressive upgrade of structural defences against flooding. For instance, the defences of Osaka have been progressively, but retroactively, upgraded in response to major typhoons and land subsidence (Okumura 1993). Some cities rely more on evacuation of vulnerable residents. In New York (ignoring parts of the conurbation within neighbouring states), up to 2.5 million people could require evacuation during a major hurricane landfall; they comprise residents and tourists in flood-prone areas as well as residents of inland mobile homes which are known to be especially hazardous during high winds (Anonymous 1993).

Subsidence

Human-induced land subsidence due to excessive groundwater withdrawal is a major problem in many coastal cities built on geologically-recent deposits (Holzer and Johnson 1985; Dolan and Goodrell 1986). The rapid growth of cities triggers accelerated groundwater exploitation. As the water table beneath the city drops formerly saturated sediments can irreversibly consolidate, the bulk density rises, and the ground surface rapidly subsides (Baeteman 1990). In low-lying coastal areas, this leads to a number of impacts including:
1) inundation (submergence) or increased flooding; and
2) impeded drainage.

In addition, subsidence causes damage and destruction of infrastructure such as pipelines and buildings.

At least eight out of the 20 coastal megacities have subsided with adverse economic consequences (Tab 3). Subsidence rates can be rapid, locally reaching one meter/decade. For instance, land subsidence around Tianjin was up to 5 cm/yr in the late 1980's (Han et al. 1993; 1995a) and locally up to 11 cm/yr in some periods (Liu et al. 1994)! This was the most rapid rate of subsidence in China and it has been recognized as a major problem which must be brought under control. The medium- to long-term implications of such change are illustrated in Japan. Although subsidence has now been largely stopped, 2 million people now live in protected areas beneath high water levels (Mimura et al. 1994). Based on the examples in Tab 3, the evolution of an anthropogenic subsidence problem can usefully be divided into four stages:
a) Stage 1. Natural subsidence only.
b) Stage 2. Increased unregulated groundwater withdrawal – enhanced subsidence triggered by urban expansion – adverse implications unrecognised.

Tab 3
Subsidence in coastal megacities

Megacity	Maximum Subsidence (m)	Date Subsidence Commenced	Policy Stage (see text)	Source
Shanghai	2.80	1921	Stage 4	Wang et al. (1995)
Tokyo	5.00	1930's	Stage 4	Holzer and Johnson (1985)
Osaka	2.80	1935	Stage 4	Tamai and Ninomya (1991)
Bangkok	1.60	1950's	Stage 3	Bird (1991)
Tianjin[1]	2.63	1959	Stage 3	Liu et al. (1994)
Jakarta	0.90	1978	Stage 2/Stage 3?	Sari (1994)
Metro Manila[2]	0.40	1960	Stage 2/Stage 3?	de Guzman (1994)
Long Beach/ Los Angeles[3]	9.00	late 1930's	Stage 4	Holzer and Johnson (1985)

Notes
[1] Maximum subsidence for Tianjin only considers the period 1959 to 1985.
[2] Results for Manila are based on the interpretation of a relative sea-level curve in de Guzman (1994).
[3] Due to oil and gas extraction.

c) Stage 3. Enhanced subsidence continues - adverse implications recognised due to progressively worsening impacts - policy response initiated - groundwater withdrawal regulated.
d) Stage 4. Controlled subsidence due to effective policy response.

While Shanghai, Tokyo and Osaka appear to have solved their problems of subsidence, this experience has not prevented similar problems developing in younger megacities and Tianjin, Bangkok, Metro Manila and Jakarta are repeating the cycle. Further, it is not uncommon for the rate of subsidence to locally exceed the maximum projected rates for global accelerated sea-level rise. This emphasizes the importance of subsidence in determining future rates of relative sea-level rise in coastal megacities.

It is likely that other coastal cities are experiencing or will experience problems of subsidence similar to those described above. Given that the physical causes and socio-economic triggers of this problem are now well understood this is avoidable. Therefore, proactive assessment and management of the withdrawal of subsurface fluid should be given a high priority in urbanized areas which are prone to this problem (Holzer and Johnson 1985; Baeteman 1990; 1994).

Coastal Megacities and Climate Change

The IPCC Common Methodology (Appendix C in IPCC 1992), or similar approaches, have been widely applied to assess potential impacts of accelerated sea-level rise (Nicholls 1995). In the context of rapidly-developing coastal cities, these assessments tend to stress unrealistic scenarios such as:
1) a one-meter rise in sea level and no other climate change,
2) the present socio-economic system, and
3) no adaptation.

These shortcomings not withstanding, these assessments are useful in demonstrating to decision makers the potential for heavy losses given global climate change.

The coastal megacities of Tianjin and Shanghai, China, exemplify many of the issues raised. Both cities are expanding rapidly as part of the rapid economic growth of China and the consequent relocation of much of the population to the coastal zone (Tab 4). This expansion is occurring in low-lying and flood-prone deltaic areas that have already experienced significant subsidence due to groundwater mining: in Tianjin this problem is not fully solved (Tab 3). Historically, floods have caused serious economic losses in both cities (Guo 1991; Ren 1991; Han et al. 1995a) and the city expansion is increasing the assets and resident population of the flood-risk areas. Actual and feared flood losses combined with subsidence have necessitated the construction and progressive upgrade of flood prevention dykes and improved water management within the dykes. The control of subsidence and the provision of flood protection is most advanced in Shanghai where a storm surge barrier has been constructed, in addition to dykes and flood walls (Guo 1991).

In Shanghai district, after a one-meter global rise in sea level, between 35 and 96% of the existing land area of over 6,000 km^2 would lie beneath high water and would be inundated in the absence of flood protection (Wang et al. 1995). The wide range reflects uncertainty about future rates of subsidence. Given the continuing growth in demand for freshwater, vigilance is necessary to maintain low rates of subsidence. The main existing urban areas would lie beneath high water without any future subsidence. Given a large surge, most of Shanghai district could be flooded during a typhoon. This threatens an existing population of 13.4 million people (1990 data), rising to a projected 21.7 million people by 2010. Enhanced protection in the form of new and upgraded dykes and flood walls to maintain the existing status quo is estimated

to cost about US $1 billion (spread over 100 years). However, improvements to drainage and associated operating costs are not included in these calculations. Further, as the city continues to expand rapidly improved flood protection measures will almost certainly become necessary. Lastly, port upgrade is not considered. Therefore, these costs must be considered as minima which may be exceeded significantly under certain scenarios. The implications of saltwater intrusion up the Yangtze River, as well as the implications of possible changes within the Yangtze catchment are not fully known.

Around Tianjin, including the entire North China Coastal Plain, a large area of up to 23,900 km^2 could be flooded given a 100-year flood and a one-meter relative rise in sea level, including the entire city (Han et al. 1993; 1995a). The population of the flood-risk area is growing rapidly with 9.2 million people in Tianjin alone (1990 data) rising to a projected 15.7 million people by 2010. Most new development is being encouraged in the most low-lying areas of the coastal plain directly adjacent to the coastal dyke. The estimated costs of enhanced protection are about US $0.5 billion for dykes, but again improvements to drainage and their running costs are not included. Therefore, as with Shanghai, this must be considered as a minimum cost estimate.

In both cases, it is apparent that it is quite difficult to develop precise assessments of the possible impacts of sea-level rise due to the rapidly evolving city landscape. However, the possible catastrophic impacts of sea-level rise are also apparent. Abandonment of any part of the coastal zone of China is unthinkable (Han et al. 1995b), so protection is the expected response to climate change. The question of how to select and optimise the potential responses remains, including the implications for all future urban expansion.

In Japan, individual city assessments are unavailable. Nationally, a one-meter rise in sea level would double the number of people living in protected low-lying areas which are beneath high water levels - from 2 million to 4.1 million - while the value of the assets in this zone would increase from an estimated 54 to 109 trillion Yen (Mimura et al. 1994). Many of these people and much of these assets are located in Tokyo and Osaka.

In all the previous examples, city authorities have already adapted to existing hazards of coastal flooding, exacerbated by high rates of subsidence. Therefore, relevant experience and the institutions necessary to deal with climate change already exist. In contrast, there is little or no comparable experience in Lagos, Nigeria, which is rapidly expanding across a low-lying coastal area already prone to flooding during the wet season (French et al. 1995). The projected rate of population growth in Lagos is much faster than either Tianjin or Shanghai, with an increase of more than 13 million people in the 20 years from 1990 to 2010 (Tab 4). Such rapid and largely unplanned change suggests that Lagos has a higher vulnerability to climate change than many other coastal megacities (Nicholls and Leatherman 1995a). Therefore, capacity building is essential to better manage this growth and hence, deal with climate change. Similar arguments may be made for some other rapidly-growing coastal cities, most notably Dhaka, Bangladesh (Tab 4).

Megacity	Population			
	1950	1970	1990	2010
Tianjin	2.4	5.2	9.2	15.7
Shanghai	5.3	11.2	13.4	21.7
Lagos	0.3	2.0	7.7	21.1
Dhaka	0.4	1.5	6.6	17.6

Tab 4 Actual and projected population growth for selected coastal megacities (data taken from United Nations Population Division, 1993)

The changing risks associated with climate change (and subsidence) point towards an alternative way to consider future impacts and policy options. In the older megacities, slow historic rises in relative sea level have been an important background effect in exacerbating flooding hazards. The Thames barrier was designed to protect London against a 1 in 1,000 storm surge until 2030 and has already been closed about 20 times (Parker 1994). However, the design did not include accelerated sea-level rise and the standard of protection may be compromised before 2030, although the probability of London being flooded remains low (Kelly 1991). In New York, flooding by the storm surge of the mid-Atlantic northeaster of 12 December 1992, including parts of Manhattan, also focused attention on this problem in an area where sea levels have risen historically at about 0.27 m/century (Lyles et al. 1988). The return period of the event was estimated at 25 ± 5 years, and this was sufficient to close down much of the city's transport infrastructure for two to four hours, including almost the entire subway system (Bocamozo, New York District, US Army Corps of Engineers, *personal communication*). While the risk of flooding will be enhanced by any rise in sea level (Leatherman 1991), a greater concern for New York is the possibility of a severe hurricane landfall after a relative lull of many decades (Coch and Wolf 1991; Anonymous 1993). As already discussed, Shanghai, Osaka and Tokyo have experienced significant subsidence of up to 5 m (ie, significant relative rises in sea level) and parts of these cities would be regularly flooded by normal high tides without flood protection. In these cases, recent global changes in sea level have been insignificant compared to local human-induced changes.

In the newer coastal megacities, urbanization is occurring so rapidly that global sea-level rise has not had time to significantly increase the risk of various hazards - although existing coastal hazards such as rapid subsidence and storm surge need to be addressed.

Response	Effectiveness Reactive Mode	Proactive Mode
'Do Nothing'	n.a.	n.a.
Planned Retreat	No	Yes
Accommodation	Yes (?)	Yes
Protect	Yes	Yes

Tab 5 Generic responses to sea-level rise (after IPCC 1990; 1992; Nicholls and Leatherman 1995b)

Other sea-level rise impacts have not been investigated systematically. For example, the provision of dependable long-term water supplies to cities menaced by saltwater intrusion requires more investigation, particularly as the associated infrastructure investment has long lead times. Beach erosion could also have significant effects in some cities. Beaches provide important recreational and protective benefits (cf. Penning-Rowsell et al. 1992), and this has often contributed significantly to amenity aspects of cities like Rio de Janeiro (Muehe and Neves 1995), Alexandria (El-Raey et al. 1995) and Miami (Turner et al. 1990).

Discussion

The problems that climate change will engender within coastal cities and megacities varies from location-to-location. Consequently, there is no single solution to these problems and each city requires individual assessment. However, climatic change brings into focus the need for a long-term strategic perspective on city development which must be integrated with other long-term, as well as short-term, concerns. These include issues of subsidence and dynamics on soft shorelines such as deltas, where declining sediment availability could cause adverse shoreline changes (eg, Turner et al. 1990). Within each city, will the tremendous investment in long-life infrastructure over the coming few decades be appropriate to conditions in 50 to 100 years? The uncertainties of climate change suggest that it would be foolish to invest large sums to counter threats that may be seen to have been exaggerated as our scientific understanding improves. However, it does suggest that it is prudent to plan with an awareness of possible coastal changes.

Many cities already have elaborate protection against flooding, and similar protective infrastructure will probably be developed in most coastal megacities over the next few decades. In these cases, climate change does not mandate disaster, rather it will make it more likely unless suitable adaptation measures are implemented (cf. Kelly 1991; Hoozemans et al. 1993; Baarse 1995). Historical evidence shows that while some coastal areas around Galveston Bay, Texas have been abandoned due to subsidence, the response to coastal subsidence has usually involved government efforts to improve protection (Holzer and Johnson 1985). This involves building dykes to prevent floods and inundation combined with improved (usually forced) drainage of the area enclosed within the dykes. Therefore, a similar response might be expected to global sea-level rise. However, it seems less likely that protection will be provided for the large and rapidly growing areas of shanty-towns and squatter camps around many cities in the developing world (Devine 1992).

A generic set of responses to sea-level rise has been proposed which can be further be considered in terms of reactive or proactive application (Tab 5). They are self-explanatory except for accommodation, which involves adaptation by changing the approach to land use as sea level rises. An example is raising each building above the new flood levels on pilings (rather than protecting them with a dyke). Traditionally, do nothing and reactive protection have been the main response to coastal problems, including those of cities. In the future, a more proactive approach needs to be encouraged. While it is likely that protection would be most favoured in cities, accommodation and planned retreat may be suitable for some locations, particularly for areas of future urban expansion along the coast. The goal should be to anticipate potential problems before they emerge and develop appropriate responses. Uncertainty remains inevitable so these responses need to be robust and flexible.

The West Kowloon Reclamation in Hong Kong illustrates one simple example of protection towards this goal - raising the reclamation level 0.8 m above previous practise to allow for sea-level rise (and/or unexpected subsidence) at an additional cost of about US $ 10 million, or less than 1% of the overall project cost (Yim 1995). Other new reclamations in Hong Kong will follow a similar design approach, while Yim (1995) recommends that existing reclamations be similarly raised as redevelopment allows. In general, infrastructure such as dykes should be designed with the possibility of future upgrade in mind - this will minimise future response costs. The potential for flooding in low-lying coastal areas also suggests that some excess drainage capacity should be included as part of new urban developments in such areas. The additional costs are minimal, while future upgrade may require rebuilding the entire system, with large costs and significant disruption. Building setbacks are one example of a mechanism for undertaking a planned retreat. The appropriate size of the setback will depend on local conditions (eg, National Research Council 1990; Caton and Eliot 1993; Rogers 1993; Nicholls and Leatherman 1995a).

Enforcement of many long-term policies such as building setbacks may be a major problem in much of the developing world. Many shanty-towns have developed irrespective of existing planning guidelines; a pattern that seems likely to continue. Why should new planning regulations be any more successful than existing

regulations? To be successful, long-term policies will have to address the broad societal processes which drive the large informal elements of many coastal megacities. This is an area where our understanding remains limited (Devine 1992).

Therefore, to develop the long-term perspective that is recommended by this paper, improved knowledge covering a range of disciplines is essential (cf. Turner et al. 1990). Long-term questions which deal with strategic issues of climate change and climate variability need to be investigated at the individual city level. Such analysis requires suitable climate scenarios which can be derived from regional climate models (eg, Qureshi and Hobbie 1994), or in their absence, via a sensitivity analysis approach. Other scenarios that include future city development patterns also need to be developed. Key questions include:

1) what are the potential consequences of climate change?;
2) how will these impacts interact with other likely changes?;
3) how can resilience and flexibility in the face of adverse impacts be increased at minimal cost while maintaining or developing functions that can meet society's requirements and preferences (eg, human settlements, natural values, recreation)?

The IPCC Common Methodology may provide a useful basis for a first assessment, although emphasis on plausible future socio-economic scenarios, the likely lifetime of different types of city infrastructure, and appropriate time scales need careful consideration.

Implementation of proactive policies towards climate change will be most efficient if it is truly integrated and comprehensive. The concept of integrated coastal zone management (ICZM) provides the basis for a process that will most effectively manage and resolve existing coastal problems and conflicts without reducing future options. It is specifically mentioned in the United Nations Conference on Environment and Development (UNCED) Agenda 21: "Programme of Action for Sustainable Development", and this is stimulating further efforts towards ICZM (eg, World Bank 1993; Pernetta and Elder 1993; World Coast Conference 1994). As climate change generally exacerbates existing problems rather than creates fundamentally new problems, solving existing problems without reducing future options is an effective response to climate change. Therefore, development of an ICZM institutional framework is recommended for each coastal megacity (and other major coastal cities). This should be an iterative process which will be progressively improved as experience grows, but it must also remain responsive and adaptive to changing conditions and human requirements of the coastal environment.

To complement these efforts, forums for the exchange of information and experience between coastal cities may have significant benefits. The continuing problems of subsidence in coastal cities, when it is both predictable and avoidable, provides an example of an issue where experience could be productively shared.

Lastly, the increasing importance of megacities may significantly change national vulnerability to climate change. Bangladesh is widely considered one of the most vulnerable countries to accelerated sea-level rise, and this has generated a number of vulnerability assessments from Broadus et al. (1986) to Asaduzzaman (1994), with further studies in progress. However, these studies have not really considered the implications of the rapid growth of Dhaka to 17.6 million people by 2010 (Tab 4), and the likelihood of further growth beyond this time frame. Urbanization needs to be better integrated into future national assessments and long-term planning.

Conclusions

Megacities are dominantly coastal in setting and this means that the problems of sea-level rise and other coastal implications of climate change are a common long-term concern. The worst impacts of climate change lie in an uncertain future, while many coastal megacities are growing rapidly today. An improved knowledge base combined with low-cost proactive measures towards climate change are recommended, applied within an integrated institutional approach towards all coastal (and perhaps regional) problems. Given the great scale of existing urbanization, some may argue that only immediate concerns should be addressed. However, without an integrated approach which considers the medium- and long-term, coastal disasters will become more likely and ultimately much more expensive reactive measures will be necessary, or some areas may have to be abandoned. Sea-level rise is an excellent symbol of the wide range of long-term coastal concerns which all need to be addressed in coastal planning.

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